Things of science

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AERODYNAMICS

Unit No. 334

AERODYNAMICS

This unit of THINGS of science contains a glider model, extra glider wing, plastic soda straw, modeling clay, two strips of thin paper and stiff paper.

We live in a sea of air some 200 miles thick. This air which surrounds the earth completely is in constant motion and although we cannot see it, we often feel it as it moves past us. The air may move quickly or slowly, in circles or a straight line, and in any direction, up or down or sideways.

Much of our lives is regulated by the movements of the air. They determine the weather, influence the structure of bridges and buildings and the safe travel of airplanes and sailing vessels.

The study of the air in motion, known as aerodynamics, is an important branch of science and is a very complex one. It involves a knowledge of engineering and materials, as well as a profound understanding of mathematics.

You have perhaps dreamed of flying high into the air like a bird, soaring out of sight and into the clouds. To some extent we have achieved this with fast-flying planes and jets which transport thousands of people back and forth across the earth. But compared to the bird, man has still

a long ways to go to master the science of flying.

You may be surprised to learn that birds and insects fly completely according to aerodynamic principles and that their movements in the air are controlled by them.

Since we live in a moving atmosphere of air, we too must pay attention to the air and its behavior and yield to aerodynamic influences.

What are these principles and how does understanding them help us make better buildings and better planes, and avoid disasters caused by changing atmospheric conditions?

In this unit, we shall observe some of the effects of air in motion on objects with special reference to the glider.

First identify your specimens.

GLIDER MODEL—in plastic wrapping
EXTRA GLIDER WING
PLASTIC SODA STRAW
MODELING CLAY
THIN PAPER
STIFF PAPER

WHAT MAKES THE AIR MOVE?

As we stand on the beach or walk in an open field, we may feel a pleasant breeze flowing by. Or if we look at the tree tops, they may be swaying in the

wind while we feel no movement in the air below. On a stormy day, the wind may rush by carrying any loose object along with it. Where does the wind come from and where does it go?

The air is made up of nitrogen, oxygen and a number of other gases and has mass—you can feel it as it passes by, and density—you can weigh it. It exerts a great pressure on the earth's surface—about one ton per square foot, but you cannot grasp it and hold it in your hand—it has no form. Yet it can act like a solid substance and uproot trees and tear apart ships in sea or sky. Air flow may be orderly or laminar, disorderly or turbulent.

Aside from providing us with essential oxygen, air by its movement most greatly affects our lives.

Many factors contribute to air movement. We can demonstrate some of them.

Experiment 1. Cut a strip ⅛-inch wide and 8 inches long from one of your pieces of thin paper. Hold the strip by one end above the cold surface of a stove. Be sure there is no draft. Note that it hangs limply and quite still. Now, turn the burner on. If you are using a gas stove, place an asbestos pad or frying pan over the burner for safety. Hold the strip

above the hot surface. Does it move as if in a breeze?

As the air close to the stove becomes heated, the molecules in the air become more agitated causing the air to expand and rise. Cold air, which is heavier than warm air, rushes down to fill the space left behind. This resulting air movement is called a convection current.

A similar reaction occurs in the atmosphere over sun-heated surfaces of the earth, but on a much larger scale. Convection currents create turbulences in the air which may vary from small whirls and eddies to huge bubbles of warm air up to a half mile wide. When bubbles of air rise up into the atmosphere cooler air rushes down to fill the space, causing a strong down draft of air. This air then becomes heated, forming another bubble which rises up and more cold air streams down. Depending upon conditions, you will have a gentle breeze or a strong wind. Birds and gliders can make use of the updraft of thermals, strong convection currents, to lift them up to great heights.

Turbulences caused by thermal convection are more pronounced in the first few thousand feet of altitude.

When the skies are clear and blue with puffs of cumulus clouds here and there,

it may look like perfect flying weather to the uninitiated, but actually the air may be very rough. The sun-warmed earth is creating huge convection currents and at the top of each column of rapidly ascending air is a tuft of cumulus cloud. Updrafts mean downdrafts are somewhere nearby. Thus a cumulus cloud indicates turbulence to the flyer and such clouds are carefully avoided.

The amount of moisture in the air also has an influence on its activity. As the air rises from the earth's surface, it expands and cools at a constant rate if there is no change in the surrounding temperature. Since colder air cannot retain as much moisture as warmer air, some of the moisture in the air condenses. This causes heat to be released and the rising air masses to expand further. The upward movement as a result becomes accelerated and more condensation takes place. If there is much moisture in the air, the cycle continues and the activity of the air becomes violent, and a thunderstorm is born. Air currents thus created may rise at speeds up to 15 to 30 feet per second.

There is yet another cause of turbulence.

Experiment 2. Take the same thin strip of paper and mount it across the

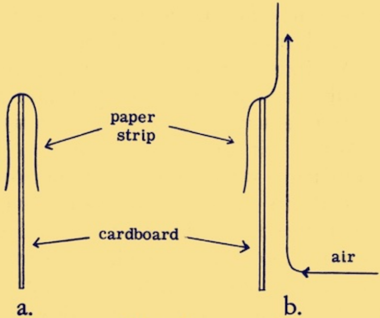

Fig. 1

top of a piece of cardboard about 9 x 12 inches in size, or a similar flat object (Fig. 1a). Hold it upright in front of a fan or air conditioner allowing the air to strike against the lower section of the cardboard. Note what happens (Fig. 1b).

This experiment demonstrates the path a wind takes when it strikes an obstacle like the flat side of a large cliff or a high mountain. It rushes up the side of the obstruction creating a strong updraft.

Experiment 3. Take another ⅛-inch strip and while holding the cardboard in the same position take the other piece in your other hand and hold it above the level of the mounted strip. Can you trace the path of the down draft?

Note that the strip falls limp without movement in certain areas behind the ob-

struction. The air does not drop straight down, but descends at a slope.

Air like every other substance on earth is subject to gravitational pull and an updraft is always followed by a downdraft.

When air crosses a mountain range, undulating waves are set in motion. The downdrafts in these mountain waves may reach speeds at times of 5,000 feet per minute. Downdrafts such as these are so strong that an airplane traveling parallel to the range can be drawn down to the ground or forced into the side of a mountain.

But if not too strong, these downdrafts can be used by birds and gliders to transport them on their way.

FLIGHT

Although aerodynamics is important in many fields, when we refer to it we usually think of airplanes and other airborne vehicles because of its close association with the problems of flight.

What the bird developed naturally through years of evolution, man has had to learn by trial and error and by research.

Experimenters learned early that man could not fly by flapping wings like a bird. And after years of study we find that the contours of the wings most ef-

fective for planes are shaped like those of the wings of birds. Planes and birds basically use the same techniques in flying.

What makes it possible for an object heavier than air to float with apparent ease in the skies?

You will find that the rules of physics govern the flight of both bird and man. Among the most important of these is Bernoulli's principle. Let us do some experiments to demonstrate this theorem, which states that as the velocity of a gas or liquid increases, pressure decreases, and as velocity decreases, pressure increases.

Experiment 4. Take the two strips of thin paper and holding them about an inch apart let them hang lengthwise. Gently blow through the space between them. Do they spread apart or do they come together? Blow harder. Do they come still closer together? The pressure between the strips is reduced as the air speeds through and the pressure of the air on the outer surface forces the strips together.

Experiment 5. Cut one strip of the thin paper crosswise into two four-inch pieces. Take one of the pieces and holding it out flat in front of you, blow

straight across beneath the paper. Does it rise or fall? Now blow straight across the top of it. Does it rise or fall?

Can you blow the paper downward by blowing harder across it? The harder you blow the higher it rises. The wind you created reduces pressure above the paper and at the same time produces a partial vacuum, causing the paper to rise up. Wind passing across the wing of a plane has a similar effect.

This experiment also shows why flat roofs are rather easily blown off by high winds.

Experiment 6. From the stiff paper, cut a circle about the size of a quarter and another just a tiny bit larger.

Make a hole the diameter of the straw in the center of the smaller disk.

Cut a two-inch piece off the cellophane soda straw and set it aside for another experiment. Insert the six-inch length into the hole you just made. Have the disk flush with the end of the straw. Secure the disk to the straw with tape.

Place the larger disk on the table and holding the disk with the straw just above it, blow hard through the straw. Does the free disk rise up (Fig. 2)?

The air passing rapidly over the lower disk reduces the pressure above it and

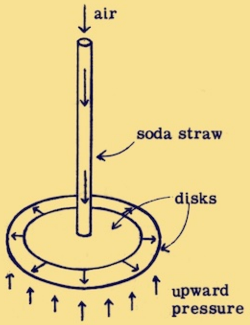

Fig. 2

causes it to rise.

Bernoulli's principle has application not only in flight but also in various other aerodynamic fields. The effect shown here is used in providing the lift for vehicles that travel on a cushion of air over land or water.

The wing of a modern plane is shaped like the diagram in Fig. 3 and is called an airfoil.

When the wing moves through the air, the air in front of it must part, some of it going above and some of it below the wing. After the plane has passed, the molecules of air go back together again. But because the upper surface of the wing is curved, the molecules flowing

Fig. 3

over the top must travel further and therefore faster than those below to reach the same point (Fig. 4).

According to Bernoulli's law, when air travels faster it exerts less pressure. Therefore, there is less pressure above the wing than below, and a partial vacuum is created. The pressure below pushes the wing upward until the pressure above and below the wing is equalized, providing the necessary lift to keep the plane up in the air.

Birds' wings are shaped in the same way. Although it may seem so, birds do not fly by flapping their wings. At the tips of their wings are special feathers that serve a similar purpose as the propellers in an airplane. When their wings are flapped, these feathers thrust the bird forward by creating a backward push. As the bird goes forward, air moves over the curve of their wings creating a low pressure area above them, lifting the bird up,

partly by the upward pull of the vacuum produced and partly by the pressure from beneath.

The reduced air pressure above the wing provides more than ⅔ of the lifting force.

When you blew across the paper in Experiment 5, the wind from below the paper moved it back and upward. In a plane, not only the atmospheric pressure but the air beneath a wing as it rushes by helps to lift it.

The propeller of an airplane is shaped similar to the wings, with the leading edge thicker than the trailing edge. As the propeller turns at high speed, it creates a low pressure area in front and pulls the plane forward, while creating a wind over the wings at the same time to provide lift.

Some backward push is also produced.

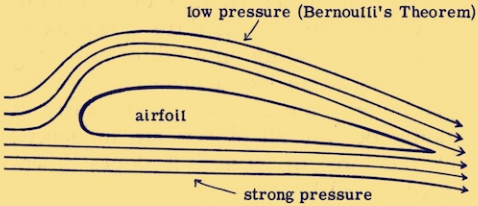

Fig. 4

Experiment 7. All forward movement results from a movement in the opposite direction. Walk a few steps and observe that as you move forward your foot pushes against the ground.

THE GLIDER

Note the parts of the glider: the wing bent slightly upward; the fuselage with slots for the wing, the smaller vertical stabilizer and the larger horizontal stabilizer.

Experiment 8. Assemble your glider carefully. Do not glue the parts together. They must be removable for the experiments. If you find it necessary to secure the wing to keep it in place, use cellophane tape which is easily removed.

The amount of lift a wing can produce is determined by several factors. First, the size of the wing. The larger the wing, the greater the amount of lift possible.

Fly your glider straight out, horizontally, and note how it floats down along a slope. It is riding on a hill of air. Since it has no motor like a plane, it must depend upon the air current to carry it along. Because all objects are influenced by the force of gravity, it slopes downward to earth.

Experiment 9. Take your two-inch

piece of straw and place it on an inclined plane using a cardboard or book. It rolls downhill, moving forward as well as downward. Without the cardboard, the straw would drop straight down. The cardboard acts as a barrier to the gravitational pull.

In the same way, your glider rides down a hill of air, pulled forward and downward. The air interferes with the pull of gravity just as the cardboard did under the straw, and the glider slides gently down.

A bird wishing to fly upward, locates a rising current of air and rests on it with wings outspread. The push of the air plus the aerodynamic lift of the bird's wings kept it afloat for hours without moving a wing.

Eventually it rises to a height where the air current can no longer lift it up, and then it goes off in a glide down a hill of air pulled by gravity, but gently buoyed by the air which prevents it from falling straight down to the earth. When it finds another upward current it soars again.

A person on a glider or sailplane, like a bird, can glide for hours in the air just by locating suitable currents.

Experiment 10. Increase the length of the wings in your glider an inch on

each side by attaching a piece of the thin paper on the end of each wing with cellophane tape. Do you get more lift? Gliding birds, such as gulls and hawks, have a much wider wingspread than do non-gliders. However, even the non-gliding birds ride the currents of air to fly from tree to tree.

Experiment 11. If the angle of a wing of an airplane is changed so that the leading edge is tilted higher, or the angle of attack is increased, the lift is increased, according to Bernoulli's theorem, since the air across the top of the wing must travel faster. The air striking the bottom surface of the wing also contributes to the increased lift. This lift is derived from Newton's Third Law which states that for each action there must be an equal and opposite action. The forces above and below the wing provide the total lifting force of the plane.

A plane increases its angle of attack by lowering the flaps along the trailing edge of the wings (Fig. 5).

Simulate flaps on your glider by attaching 1¾-inch by ¾-inch strips of the thin paper to the inner section of the trailing edge of the wings.

Bend the flap down just slightly.

Does the glider acquire more lift?

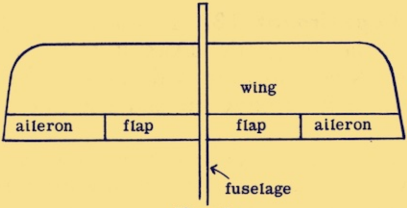

Fig. 5

If the angle of attack is increased beyond a certain critical point, the lift will disappear and the plane will stall and fall to the earth.

The lift is produced by decreased pressure above the wing. The partial vacuum thus produced keeps the airstream close to the wing. If the angle of attack is increased too much, the airstream can no longer be held to the wing and breaks away and the lift no longer exists, causing the plane to stall.

To avoid this, small slots are placed near the upper surface of the wing. The air passing through the slots is forced to travel faster creating reduced pressure and the airstream will flow closer to the wing.

Experiment 12. Bend the flaps to about 45°. Now fly it. Does it stall?

Speed is the most important factor in lift. The faster a plane or bird flies, the greater the lift produced.

Experiment 13. Thrust your glider into the air gently. Does it travel very far? Now thrust it with greater force. Does it have more lift and rise into the air?

The pull of gravity must always be taken into account. If the upward force of the lift and downward pull of gravity are in equilibrium, an airplane, bird or glider will remain at the same altitude. To climb upward, the lifting force must be greater than the pull of gravity and to travel downward, the lift must be less than gravity.

Most birds take off into the wind. Can you explain why?

At take-off a plane needs a greater lifting force to counteract the gravitational pull. To provide for this, a plane is equipped with ailerons and flaps to extend the wing surface and travels rapidly along the ground to force the air molecules to pass over the wings fast enough to create the necessary lift.

Experiment 14. Attach ailerons to the trailing edge of the wings of your glider and then fly it with both flaps and ailerons extended. Does this give the glider more lift?

As an airplane moves through the air, it must push air particles out of its way.

In doing this, the plane experiences a force called resistance. This resistance is known as drag and opposes the forward motion of the plane. As the airplane flies, the molecules of air slide past each other and rub against each other. This rubbing creates friction and produces heat which at high speeds may reach temperatures of 200°F. or more.

Various factors contribute to drag when a plane is in flight and the structure of planes are so designed to minimize drag and friction as much as possible.

Experiment 15. To be properly balanced, the wings of a plane or glider must be equal on each side.

What happens when you make one wing even slightly longer than the other? Push the wing about ⅛ of an inch to the right. What effect does this have on the glider's flight path? In which direction does the glider turn? Why?

Experiment 16. Landing a plane is as dangerous as taking off. First of all, the plane must be slowed against the pull of gravity. To do this, the plane's flaps come into action on the wings as well as the elevators on the back of the horizontal stabilizer.

Place a narrow flap like those on the wings along the length of the trailing edge of the horizontal stabilizer to simulate the elevators.

Bend the ailerons, flaps and elevator down to about 45°. Is the landing of the glider slowed? Change their angles and try to regulate the speed of landing.

Experiment 17. Lower the elevator only. How does this affect its flight? Does raising the elevator upward have any effect on the glider's flight?

Experiment 18. A plane, just like a boat has a rudder behind it to guide it in the direction desired.

A rudder is hinged to the back of the vertical stabilizer.

Place a one-fourth-inch extension on the back of the vertical stabilizer, exactly in line with it and fly the glider. It should fly straight.

Now bend the rudder to the left and fly the glider. In which direction does it turn? Bend the rudder to the right and fly the glider again. Which way does it turn this time? Regulate the rudder to obtain the exact amount of turn desired.

Experiment 19. When a plane is turned, it must be banked or tilted to prevent skidding. Modern planes are

equipped with ailerons which can be moved up or down. When a pilot wishes to tip the plane, he raises one aileron and lowers the other. The wing with the aileron pushed up goes downward and the wing with the aileron pushed downward is raised.

Try this with your glider. Can you adjust the ailerons so that the glider will bank without crashing?

A plane must above all be stable. It must be able to fly in a straight path at a steady speed and without the aid of a pilot.

Experiment 20. Replace the wing you have on the glider with the extra wing. Note that it is flat and not bent like the original wing. Fly the glider. Does it fly in a straight path? It should.

Now remove the vertical stabilizer. What happens to the glider? It has lost its stability and crashes.

Replace the rudder and remove the horizontal stabilizer. What happens to the glider's stability?

Experiment 21. Reassemble the glider. Place it across a narrow flat edge or your finger and find the point at which it is in exact balance and will neither fall backward nor forward and where it will swing around freely as if

on a pivot. This point is its center of gravity, or CG.

The center of gravity is very important in maintaining the stability of a plane or glider.

Take a piece of clay about a half-inch square and place it behind the center of gravity. Fly the glider. What happens?

Place the clay in front of the center of gravity. Will the glider fly properly this time? It takes a nose dive.

In both cases you have destroyed the balance of the glider and it crashes each time.

Experiment 22. Place the clay at different parts on the glider and note the effects. What happens to the glider's flight when the whole piece of clay is placed exactly on its CG?

Experiment 23. With a sharp instrument make a line across the exact center of the extra wing. Bend the wings upward to form a shallow V-shape.

If the wing splits at the center secure it with cellophane tape. Insert the wing into the glider and fly it. Is it more stable than with flat wings? Do you get a smooth glide?

The dihedral shape produces more lift and also provides more stability.

The dihedral makes a plane fly straight

instead of circling.

Experiment 24. Raise the sides of the dihedral higher. Does the stability increase or decrease? Why?

Experiment 25. How can we make a plane circle? Raise one wing of the dihedral and have the other horizontal. In which direction does the glider turn? Can you make it circle in the opposite direction?

Experiment 26. Straighten out the wing and measure inward from the ends of the wing one inch. Cut off the one-inch sections with scissors. Replace the pieces with cellophane tape but tilt the tips upward (Fig. 6).

Fig. 6

Replace the wing in the slot and fly the glider again.

Does this change in the wing improve its flight?

These experiments demonstrate some of the principles of aerodynamics and

their applications.

It is a fascinating field of study related to various aspects of our lives. Many books have been published on this subject, if you wish to pursue the subject further. A few of them are listed below.

Aerodynamics of the Airplane, Millikan, Wiley, N.Y. 1941.

Birds and Planes: How They Fly, Ava Morgan, Thomas Y. Crowell Co., New York, 1953.

Mastery of the Air, Sir Graham Sutton, Basic Books, Inc., New York, 1966.

The Physical Nature of Flight, Ray Holland, Jr., W. W. Norton and Company, Inc., New York, 1951.

"Simple Approach to Aerodynamics," *American Modeler,* May/June, Vol. 63, No. 3, p. 38.

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